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PROPAGATION AND SOURCE PARAMETERS
FROM LONG-PERIOD HIGH-GAIN
SEISMOGRAPHS

Agustin Udias

Barcelona University

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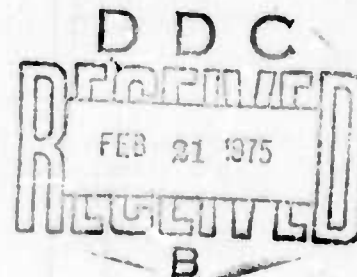
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INTRODUCTION

Since 1970 eleven stations with high-gain (magnifications up to 150.000) long-period (peak between 30 and 50 s) systems recording in analog and digital form have been put in operation (Savino et al., 1972). These stations, that will be referred to as HGLP, have been used in the determination of propagation and source mechanism parameters, comparing their performance with that of the WWSSN stations. The parameters selected in this study are for the propagation characteristics group and phase velocities of surface waves and attenuation and for the source, the dimensions of the fracture plane, seismic moment and the stress conditions. Because of the response of the HGLP systems which peaks at about 30 sec, special emphasis has been placed on the determination of the about mentioned parameters by means of surface waves.

A very important step in the analysis of the HGLP data is that of the preliminary processing which involves analog to digital conversion, filtering and spectral analysis. Reduction to ground motion requires also knowledge of the response characteristics of the systems. The HGLP instruments have two outputs, one analog (HGLP-ANL) with conventional photographic recording the other digital (HGLP-DIG) on magnetic tape. Digitalization of the analog records have been done from enlarged copies of the microfilm

In this respect the data from earthquakes relatively large and near to the station are practically impossible to analyze. Amplitudes are too large, lines faded, and traces entangled. The digital outputs should solve this problem, but it creates some of its own.

In order to study the capabilities of the digital outputs of the HGLP stations, the digital tapes in file at the Lamont-Doherty Observatory were studied. We have selected for our study 8 earthquakes and 5 nuclear explosions. Of those only 37 records were found of any use. Some of the problems found were that the records were not in the Lamont file, were copies defective, failures were present in the digital system, and magnification was too low. The process of finding the proper place in the tapes is also very time consuming, since there is not a fast search system. Outputs of the digital data in magnetic tape and printed form are now being analyzed. Another problem encountered in using HGLP-DIG data is the variation of the ground motion. In the ALQ (Albuquerque Observatory) station the values found in 10 calibrations from Oct 73 to Mar 74 gives for the magnification at 30 sec in counts per micron values ranging from 802 to 1232 in the Z component, 512 to 852 in NS and 593 to 965 in EW (A. Murphy, personal communication). It is not known whether the changes were the result of modifications made to the system or spontaneous changes. If the latter is true, large errors can be introduced when using digital data from stations where calibration is not repeated so often. This lack of stability in the digital system should be reflected in the comparison of the source parameters which require ground motion reduction as determined from analog and digital records.

Determination of source parameters

For many years all that could be found about the mechanism of earthquakes was the orientation of two nodal planes of P waves, one of them corresponding to the plane of fracture and the energy released as seismic waves derived usually from the value of magnitude. Progress in the study of focal mechanism has led to the definition and determination of several parameters describing more fully the processes at the source of earthquakes (Aki, 1972). These are the dimensions of the plane of fracture, the seismic moment, apparent average stress and stress drop. Of the several methods proposed for the determinations of these parameters we have selected two which are mutually independent, one based on the spectral amplitudes of the Rayleigh waves and the other on the amplitude and form of the shear wave spectrum.

Method of spectral amplitudes of Rayleigh waves

Following the work of Ben-Menahen, Jarosch and Roseman (1970) the Seismic moment can be expressed in terms of the spectral amplitudes of the vertical component of the Rayleigh wave in the form

$$M_0 = \frac{\mu U_z(\omega)}{\frac{\exp(-\gamma_R \Delta - i\pi/4)}{\sqrt{\sin \frac{\Delta}{\alpha}}} (P_R P_R + S_R S_R + i Q_R Q_R)} \quad (1)$$

The parameters of this equation are given in a convenient form in the tables of the same article.

The length of the fault can be obtained assuming a propagating rupture of rectangular form, from the "directivity function".

This function has been defined by Ben-Menahen (1961) as the ratio of the spectral amplitudes of surface waves corresponding to rays leaving the focus in opposite direction. The limitation of using only data from stations 180 degrees apart in azimuth is not necessary in many cases (Udías, 1971). If α is the angle between the azimuths of two stations the length of the fault is given by

$$b = \frac{c_R}{f_{\max} \left(\frac{c_R}{v} - \cos(\theta + \alpha) \right)} = \frac{c_R}{f_{\min} \left(\frac{c_R}{v} - \cos \theta \right)} \quad (2)$$

where f_{\max} and f_{\min} are the frequencies of the first maximum or minimum of the directivity function, v the rupture velocity, c_R the phase velocity and θ the azimuth from the fault plane.

Method of shear-wave spectrum, corner-frequency

The amplitude and form of the spectrum of shear waves have been related to the values of certain parameters at the source (Aki, 1972). The spectral corner-frequency f_0 , or frequency where the spectrum bends from a constant value Ω_0 at low frequencies to a diminishing value with frequency. (Brune, 1970), and the value of Ω_0 itself are the two parameters of the spectrum related with source characteristics. A third parameter obtainable from the spectrum is ϵ which controls the high frequency decay of the spectrum. Accepting the general validity of Brune's model and the physical interpretation given by him to the three parameters f_0 , Ω_0 and ϵ they can be used in the specification of the characteristics of the source of earthquakes (Hank and Thatcher, 1972).

The spectral amplitude Ω_0 is related to the seismic moment by the formula

$$M_0 = 4\pi \rho \beta^3 R \Omega_0 \quad (3)$$

The corner frequency f_0 is related to the radius of the equivalent circular fault area r by

$$r = \frac{2.34 \beta}{2\pi f_0} \quad (4)$$

The stress drop, difference in shear stress acting before and after an earthquake is given by

$$\Delta\sigma = \frac{7M_0}{16r^3} = 106 \rho R \Omega_0 f_0^3 \quad (5)$$

The parameter ϵ is related to the ratio of the stress drop $\Delta\sigma$ to the shear stress difference on the fault surface, or effective shear stress σ_{eff}

$$\epsilon = \frac{\Delta\sigma}{\sigma_{eff}} \quad (6)$$

If ϵ is taken to be unity, the apparent average stress defined by Wyss (1970) as

$$\eta \bar{\sigma} = \mu \frac{E_s}{M_0} \quad (7)$$

is given in terms of f_0 and Ω_0 by,

$$\eta \bar{\sigma} = 21.1 \rho R \Omega_0 f_0^3 \quad (8)$$

This formula is also valid to a certain approximation for the cases where $\epsilon < 1$. In all these formulas β is the shear wave velocity and R the reference hypocentral distance.

Application to the earthquake of 6 June 1972

Origin time and location:

6 June 1972, 05:25:50.2

32.9 N , 39.9 W, h = 33

$m_b = 5.5$

Orientation of nodal planes:

plane A: N 66 W - 68 NW

plane B: N 19 E - 76 NE

Seismic moment

Seismic moment has been calculated from the values of the smoothed spectral amplitudes of the vertical component of Rayleigh waves corresponding to periods of 50 and 100 seconds and from the low-frequency limit of the amplitude spectrum of shear waves. Results are listed below:

Rayleigh waves

Station	M_0 dyne-cm	
	$T = 50 \text{ sec}$	$T = 100$
ALQ HGLP-ANL	10^{25}	$4 \cdot 10^{24}$
TLO HGLP-ANL	$3 \cdot 10^{24}$	$3 \cdot 10^{24}$
KON HGLP-ANL	$3 \cdot 10^{24}$	
ALQ HGLP-DIG	$3 \cdot 10^{24}$	$.6 \cdot 10^{24}$
ALQ WWSSN	$3 \cdot 10^{25}$	10^{25}
LPB WWSSN	$8 \cdot 10^{23}$	$2 \cdot 10^{23}$

Shear waves

KON HGLP-ANL	$5 \cdot 10^{24}$
ALQ HGLP-DIG	$6.5 \cdot 10^{24}$

Agreement between the different values is good. As an average the value of M_0 is $3 \cdot 10^{24}$ dyne-cm. This agrees with values obtained for the moment in the same magnitude range by other authors (Aki, 1972). The agreement between the values obtained from the digital and analog records of the HGLP is also good, as it is between those found using surface and shear waves.

In figure 2 we show the spectra of the Rayleigh waves recorded at the same station (ALQ) by the WWSSN, HGLP-ANL and HGLP-DIG instruments, reduced to ground motion. The spectrum of the HGLP-DIG gives smaller amplitudes for periods shorter than 26 sec.

Length of faulting

Length of faulting has been calculated from the directivity function of Rayleigh waves and from the corner frequency of shear

waves. Results are listed below:

Directivity

Stations	b km	v km/sec
KON/TLO HGLP-ANL	31	1.5
	40	2.1
	52	3.0
KON/ALQ HGLP-ANL	46	1.0
	68	1.5
	89	2.0
TLO/ALQ HGLP-ANL	42	1.5
	52	2.0
	70	3.0

Corner frequency

	r km
KON HGLP-ANL	20
ALQ HGLP-DIG	13

The values from the directivity depend on the assumption of a velocity of fracture v . In previous studies (Udias, 1972) we have seen that for this range of magnitudes the most consistent value of v is about 2 km/sec. This method assumes a rectangular fault with a propagating fracture. As the value from KNO/ALQ is higher than the other two, we can safely take $b = 45$ km. From the corner frequency we obtain the radius r of the equivalent circular fault. Taking the mean of the two values $r = 16.5$; this gives an

an area of 855 km^2 for the fault surface. This area in the rectangular model of length 45 km will result in a fault width of 19 km, which is also a reasonable value for a shallow shock of this magnitude.

Stress-drop and apparent-stress

From the corner frequency we can also obtain values for the stress drop and apparent stress. Using the HGLP records of two stations the values obtained are

KON HGLP-ANL	$\Delta\sigma = 0.27 \text{ bars}$	$\eta\bar{\sigma} = 5 \cdot 10^4 \text{ dyne/cm}^2$
ALQ HGLP-DIG	$\Delta\sigma = 4.1 \text{ bars}$	$\eta\bar{\sigma} = 8 \cdot 10^5 \text{ dyne/cm}^2$

These two values are somewhat low specially that of KON. The value from ALQ is nearer to what is usually found. The apparent stress can be found directly from the values of the energy and the moment, using equation (7).

Using a value for $\mu = 3.3 \cdot 10^{11} \text{ dyne/cm}^2$ and for the energy that derived from the magnitude according to the formula

$$\log E_s = 5.8 + 2.4 m_b$$

which gives

$$E_s = 10^{19}$$

the resulting value for the apparent stress is

$$\eta\bar{\sigma} = 1.1 \cdot 10^6 \text{ dyne/cm}^2$$

This value agrees better with other values of this parameter for similar magnitudes. The smaller values found from the corner frequency may be due in part to the fact that the expressions used assumed that $\epsilon = \text{unity}$, which may not be a realistic assumption.

Up to this point we can point to the good possibilities

offered by the HGLP record in the analysis of source parameter from shocks in the magnitude range $5.0 < M < 6.0$. So far it has been found also that outputs of the digital system give very consistent results.

Propagation parameters

Two other areas that are under analysis to test the reliability of HGLP data are the determination of absorption coefficient and anelastic properties along the propagating path and the group and phase velocities of surface waves. Computer programs for the processing of the data have been prepared. These involved the use of multiple filter techniques to determine the group velocities of the energy contained in narrow bands of frequencies, of sliding filters to eliminate unwanted disturbances in the surface wave signal and programs to calculate phase velocities by different methods.

These programs will be applied to the analysis of phase velocity along the path from the two HGLP stations in the Mediterranean TLO and EIL. This path crosses the Mediterranean sea and it is expected that the data will furnish new information for the interpretation of the structure of this complicated tectonical area. Since these two stations are also WWSSN stations comparison of both type of data will show the improvement of the results due to the use of the HGLP stations.

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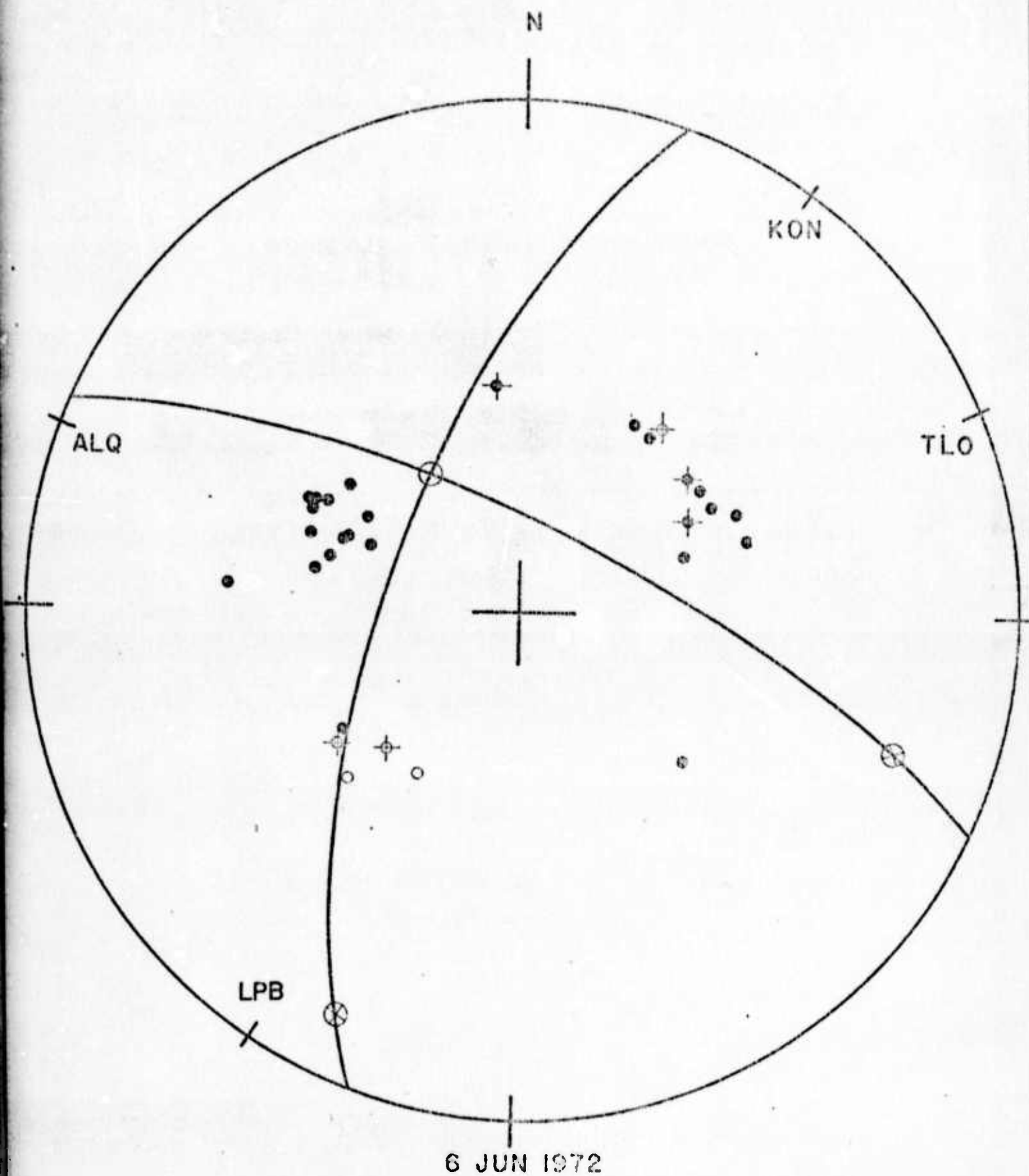


Figure 1. Orientation of the focal mechanism solution of the earthquake of June 6, and azimuthal position of the stations used in surface wave analysis.

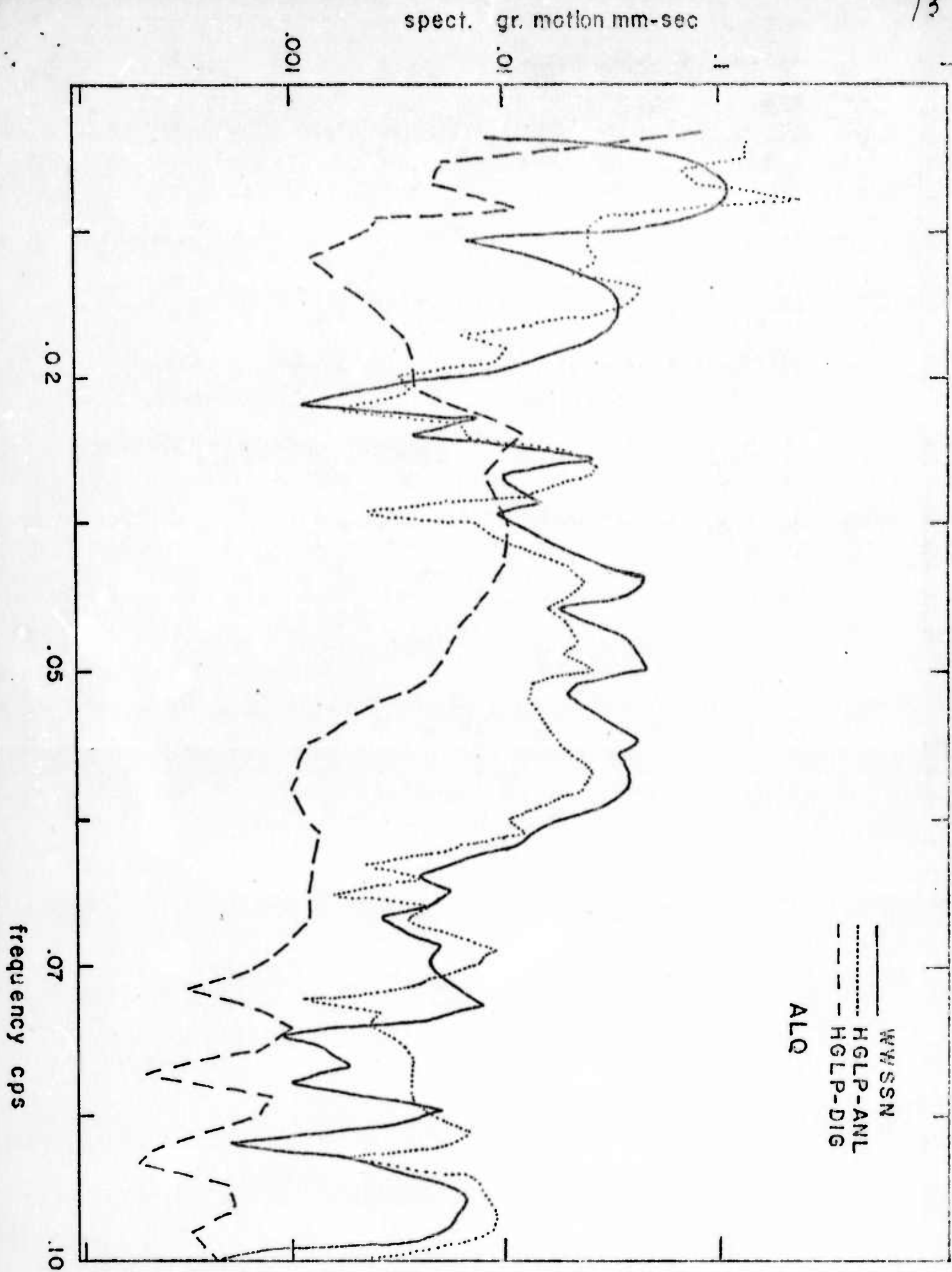


Figure 2. Rayleigh wave spectrum reduced to ground at ALQ (Albuquerque, N.M.)

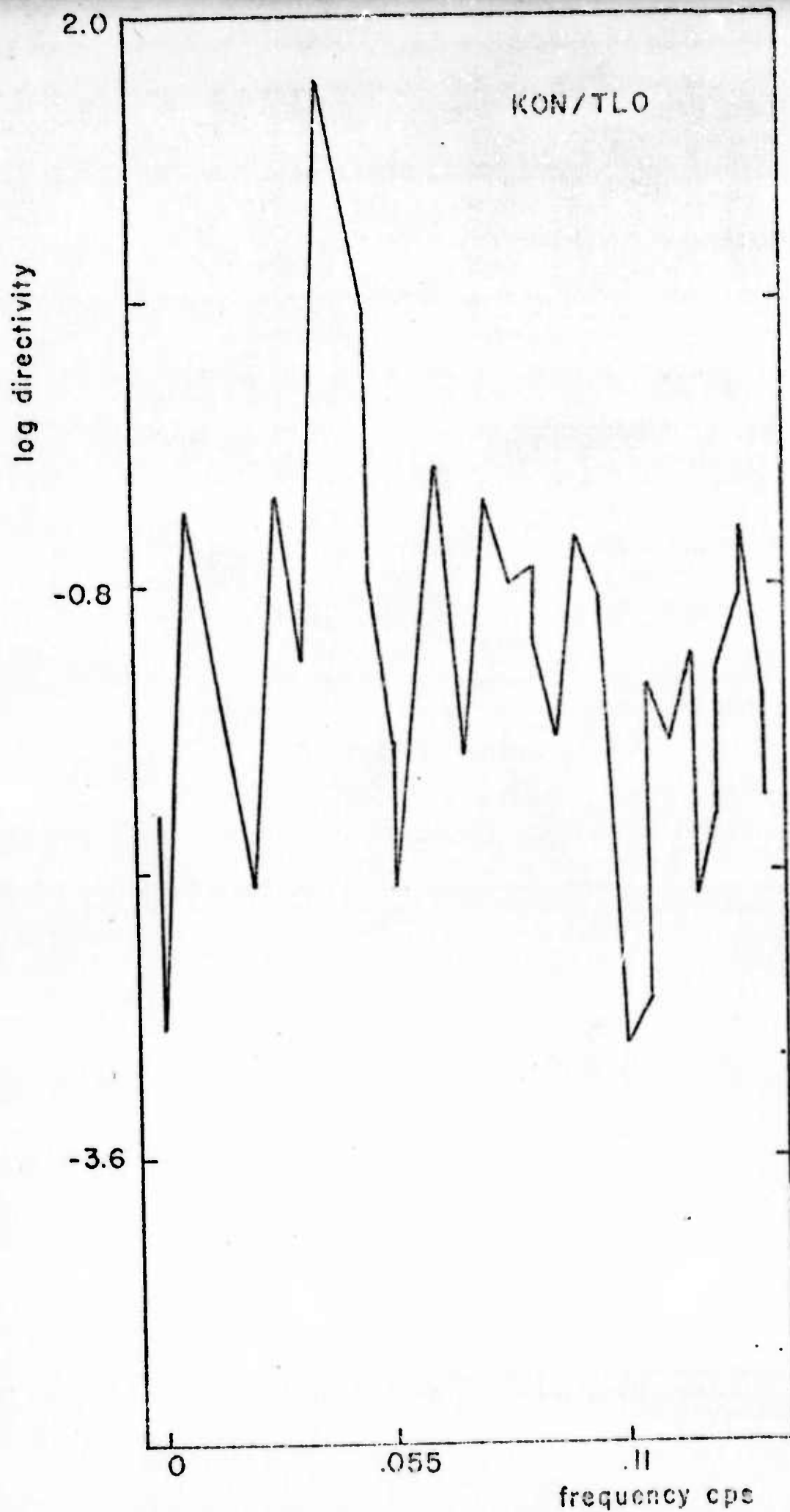


Figure 3. Directivity Function For KON/TLO